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Title: Bedrock Geology of the Gardiner 15' Quadrangle, Maine

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INTRODUCTION

The Gardiner Quadrangle is located at the juncture between the Late Ordovician(?) to Devonian metasedimentary sequence of the Merrimack Synclinorium to the northwest and an older (Cambro-Ordovician ?) sequence of distinctly different metavolcanic and metasedimentary rocks to the southeast. The latter units belong to the Cushing Formation, which, together with an uncomformably overlying sequence of rocks, comprise the Casco Bay Group of Brookins and Hussey (1978).

In recent interpretations of the geology and evolution of the Northern Appalachians, the Cushing metavolcanics are considered to represent Avalonian basement with age and lithologic affinities to rocks mapped east of the Clinton-Newbury fault zone in Massachusetts and rocks exposed on the Avalonian peninsula in Newfoundland. In a discussion of the Canadian Appalachians, Schenk (1978, p. 112-113) implies that the Cushing metavolcanics belong to the "Avalon Zone", and the Cape Elizabeth Formation and the units which overlie it belong to the "Gander Zone". Hence, the rocks of the southeastern half of the Gardiner Quadrangle are, according to Schenk, a part of the continental mass of Avalonia which was juxtaposed against rocks of the North American continental margin as it existed after the Ordovician Taconic Orogeny. This juxtaposition by plate tectonic processes culminated in the closure of Iapetus during the Devonian Acadian Orogeny.

Evidence of this kind of continent-continent collision is obscure in the mapped relationships between the rocks exposed in the quadrangle. The presumed join between North American cover rocks resting on Grenville basement and Gander Zone cover rocks resting on Avalonian basement follows a topographic low extending southwest from the City of Gardiner along Cobbosseecontee Stream and Pleasant Pond. It is, in the mapping here discussed, considered a thrust fault of pre-Acadian or early Acadian age with the rocks of the Merrimack Sequence (i.e., the Vassalboro Formation) thrust eastward over the rocks of the older Cushing Formation. This presumed thrust and younger high angle faults which cut and offset it are part of a major fault zone which extends at least from the west side of Penobscot Bay to the Clinton-Newbury and Lake Char fault of Massachusetts and Connecticut respectively. In Maine, the zone has been named the Norumbega Fault (Stewart and Wones, 1974). Post-Acadian cataclasis and mylonitization of the rocks within the fault zone, including most notably the mylonites in the Blinn Hill granodiorite just east of the Gardiner Quadrangle, as well as epicentral locations of recent earthquakes suggest that the zone has been active for a long interval of geologic time. The seismic data suggest that it is at present a zone where sudden release of stress continues to occur.

The sense of motion and cumulative displacement along the Norumbega Fault are unknown at present. Geologic observation in southwestern Maine generally suggests that initial thrust or low angle reverse faulting may have ceased in mid-Devonian time and been followed by later high angle fault displacement. D. R. Wones (personal communication, 1981) contends that a significant strike-slip component of movement is required by relationships mapped just north of Penobscot Bay.

If the eastern half of the quadrangle is indeed underlain by an older sequence of rocks, one might reasonably expect that they would record a more complex deformational history than the rocks to the west. In the Gardiner Quadrangle this cannot be demonstrated. Either the sequence of Acadian fold events has obliterated pre-Acadian deformational history or the resolution of the stratigraphy within the Cushing and Cape Elizabeth Formations is not sufficiently detailed to demonstrate an earlier history.

The rocks of the area show three periods of folding--as has been demonstrated elsewhere in southwestern Maine (Osberg, 1980). The first period involved recumbent folding on a regional scale and is responsible for the inversion of the stratigraphic sequence of Merrimack Group rocks over broad areas. This was followed by a period of upright folding about gently SW and NE plunging axes which controls the spatial distribution of lithologic units. A strong axial plane foliation is associated with the event, as is regional metamorphism to sillimanite grade. Structures produced in this episode of folding have dimensions on the order of 30 km along the axial trace and 2-3 km across strike. A third fold event involved the refolding of earlier structures to produce cross-folds on an outcrop or slightly larger scale. These structures have a weak axial planar cleavage in granofels and produced strong crenulation of the micas in metapelites. Axes plunge northwest, and, in the Gardiner quadrangle, axial surfaces dip variably northeast.

The final episode of folding is temporally related to the emplacement of grantic plutons and associated pegmatites. Where pegmatites are abundant in outcrop, late fold structures are prominent. However, the folds are also seen in areas that lack granite or a significant amount of pegmatite. Their presence in such areas may be related to the presence of an immediately subjacent granite. The complete absence of these structures over wide areas of the quadrangle argues in favor of their development as a consequence of pluton emplacement. An alternate interpretation, namely that the folding and pluton emplacement represent separate manifestations of a final pulse of the Acadian Orogeny, has been suggested by Moench and Zartman (1976).

PREVIOUS WORK

Previous geological work in the Gardiner quadrangle includes an aeromagnetic study by Wing (1959) of approximately the northeastern 1/9th of the quadrangle. This study was presumably prompted by the numerous sulfidic exposures in the area immediately south of the City of Gardiner, many of which contain a significant amount of pyrrhotite. (A brief discussion of the magnetic patterns shown by this study is included in the appendix of this report.)

Barker (1965) mapped the alkalic rocks in Litchfield in the north-central portion of the quadrangle. A nearly circular pluton, approximately 3 km in diameter, was mapped largely on the basis of large glacial erratics which Barker considered to be essentially in place. The pluton occupies a small topographic depression and a few scattered outcrops provided the means of "calibrating" this approach to mapping. Five phases or petrologic variants of the pluton were thus identified and their petrogenetic significance discussed. Barker considered the syenite to belong to the White Mountain Magma Series on petrologic grounds, and noted that the pluton was the easternmost of four compositionally similar bodies. The others are located at Cuttingsville, Vermont; Red Hill, New Hampshire; and Pleasant Mountain, Maine. As discussed later (p. 10), a Devonian age is assigned to this pluton.

Heinonen (1971) mapped the geology of the Tacoma Lakes area. The area is located in the northwest corner of the quadrangle and includes a portion of the Lewiston quadrangle to the west. The pattern of units shown by him correlates reasonably well with that represented on the map accompanying this report. Heinonen considered the rocks of the Tacoma Lakes area to be in the second sillimanite zone of regional metamorphism. Sufficient petrographic work has not been done to assess the validity of this statement. However, staurolite is absent from the metapelites of the area and sillimanite is abundant. In one thin section from the northwest corner of the quadrangle sillimanite occurs as fibrolitic masses within a foliation defined by parallel orientation of biotite and minor fine grained muscovite. Muscovite also occurs as randomly oriented coarse grained ovoid patches pseudomorphing staurolite (?). There is, then, evidence that the rocks are at least in the upper sillimanite zone of regional metamorphism.

In addition to work done in the quadrangle, previous work done in adjoining areas has been helpful. The Wiscasset quadrangle to the east has been mapped by Hatheway (1969). Of particular interest are the cataclastic zones mapped by him since one continues to the southwest and in the Gardiner quadrangle is referred to as the Eastern River Fault. Also his outcrop location map has proved extremely helpful in terms of attempting to trace the stratigraphy within the Cushing Formation on strike to the northeast. The Lewiston quadrangle to the west has been mapped in part by Hussey and Pankiwskyj (1980), and Hussey (1981a) has done reconnaissance mapping in the northern half of the Bath quadrangle which adjoins the Gardiner quadrangle to the south. In the Orrs Island 7.5' quadrangle, the SW 1/4 of the Bath quadrangle, Hussey (1965) divided the Cushing Formation into three members. These include the upper Sebascodegan Member, a middle Bethel Point Member, and a lower Yarmouth Island Member. It is uncertain whether these stratigraphic units are present in the Gardiner quadrangle or whether they disappear on strike to the northeast beneath the uncomformably overlying Cape Elizabeth Formation. Alternatively, displacement along one or more of the faults comprising the Norumbega Fault Zone may expose a different stratigraphic interval of the Cushing Formation in the Gardiner quadrangle.

STRATIGRAPHY

ROCKS OF THE CASCO BAY SEQUENCE

Cushing Formation. The oldest units mapped belong to the Cushing Formation. These outcrop in a north-south trending belt bounded on the west by a complex system of pre- and post-metamorphic faults which juxtapose the Vassalboro Formation against various units of the Cushing. To the east, units of the Cushing disappear beneath the uncomformably overlying Cape Elizabeth Formation or are in fault contact with the latter.

The Cushing Formation was originally named the Cushing Granodiorite by Katz (1917). Exposures mapped by him on Cushing Island were considered to represent a deformed intrusive rock. Subsequently, Bodine (1965) and Hussey (1965) reinterpreted these and other lithic types spatially associated with them as comprising a complex sequence of metamorphosed volcanic and volcaniclastic rocks. Distinct evidence of the pyroclastic nature of at least a portion of the Cushing can be seen in the fragmental textures clearly seen in exposures in Cape Elizabeth south of Portland Head Light and at Lookout Point in Harpswell. Units mapped as Cushing in the Gardiner quadrangle are so designated because of their position "between" the Vassalboro and Cape Elizabeth, i.e., because of regional lithologic and structural relationships, rather than because of a tracing of the units continuously from Casco Bay (and Cushing Island) to the northeast.

In the map area the Cushing Formation is divided into the Richmond Corner, Mt. Ararat, and Nehumkeag Pond members. The Richmond Corner member is assumed to be the oldest, although there is no evidence bearing on the relative ages of any of the map units recognized in the Cushing.* This member consists predominantly of garnet-rich biotite-plagioclase-quartz gneiss with intervals of hornblende-biotite amphibolite. Minor garnet-magnetite-quartz meta-coticule is also present. In the southwest portion of the quadrangle on Hornbeam Hill, as well as on several small elliptical hills to the north and northeast, this member contains coarse-grained, massive feldspathic garnet-biotite granofels in which feldspar megacrysts are quite prominent giving the rock a "popcorn" texture. Preliminary thin section examination of this lithology suggests that it is a metamorphosed intrusive igneous rock. The member is named for exposures north and south of Richmond Corner along Route 201. It is also well exposed on both sides of that highway 5 km. north of Richmond Corner.

The Richmond Corner Member is separated from the Mt. Ararat Member by a thin marble unit and by a rusty weathering zone containing pyrrhotite-graphite-sillimanite. The latter is not continuously exposed and may be a discontinuous unit along one or both of the contacts of the marble. The rusty weathering metapelite is well exposed at Richmond Corner, i.e., at the intersection of Routes 197 and 201.

The Mt. Ararat Member of the Cushing is named for exposures on the Sage Base of the U.S. Navy just north of Mt. Ararat school in the Bath 15' quadrangle. It is also well exposed along Interstate 95 just south of the Richmond-Bowdoinham interchange. The Mt. Ararat Member is a distinctly banded gneiss of medium to dark gray color. Dark micaceous

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*The fact that stratigraphic sequence in the Cushing is assumed is an important point. In the drafting of a map such as the one which accompanies this report, the stratified rocks are listed conventionally in order of relative age. Thus, in the cartographic process one must make a commitment as to relative age. In this case, an entirely arbitrary commitment has been made with respect to the various lithologies recognized within the Cushing.

intervals containing biotite with varying amounts of hornblende alternate with lighter quartzo-feldspathic bands. Layering is on a scale of 2-10 cms. Within this member are numerous amphibolites consisting of feldspar and hornblende. Calc-silicate pods and lenses are occasionally present but are not characteristic of the amphibolites. Assuming that this unit represents a series of flows of intermediate to basic composition, these lenses may represent calcite filled amygdules which have been deformed and metamorphosed. Alternatively, the amphibolites may be layers of metamorphosed basaltic ash (Hussey, personal communication). In any case, this lithology, which comprises a significant amount of the Mt. Ararat member (40%), appears to be part of the original volcanic stratigraphy.

At least one rusty-weathering pelitic horizon, i.e. a garnet-sillimanite-biotite schist, occurs within the Mt. Ararat member. It is exposed along Sedgely Brook in the SC 1/9 of the quadrangle where I-95 "straddles" the brook. The outcrop width of the rusty weathering zone is on the order of 30 - 40 meters. Exposure of bedrock to the northeast and southwest is insufficient to establish the continuation of this zone for any significant distance along strike.

The Nehumkeag Pond Member of the Cushing Formation overlies the Mt. Ararat member. This member is composed principally of weak to discontinuously foliated, buff to slightly rusty weathering, quartzofeldspathic gneiss. Muscovite, and less commonly biotite, are present as anastomosing wisps of mica within the predominantly massive, fine-grained gneiss. This unit is thought to represent a sequence of metamorphosed felsic volcanics although recognizable pyroclastic textures have not been identified. Much of the rock exposed on Swan Island is considered to be part of this member but it is best exposed north of Nehumkeag Pond in the Wiscasset quadrangle. In that quadrangle good exposures exist north of the Pond near Goodspeed Cemetery on Route 194 and along the ridge paralleling the Eastern River along its east side north of the town of Dresden Mills. At these locations the rock is slightly rusty weathering due to the presence of scattered pyrite. It has a characteristic blocky, prismatic break with the bounding surfaces being joints and the poorly defined weak foliation mentioned above.

In the Gardiner quadrangle two metasedimentary units within the Nehumkeag Pond member are perhaps better exposed than the lithology discussed above. One is an impure marble whose outcrop pattern defines a re-folded fold near Bowdoinham in the south central part of the quadrangle. The other is a rusty weathering pelitic unit well exposed along the Abagadasset River west of Richmond. In exposures along the river the unit contains the assemblage garnet-sillimanite-muscovite and a considerable amount of graphite and pyrite. Exposures north of Richmond on Hathorn Hill are similar although a considerable amount of pegmatite in part masks the nature of the Nehumkeag Pond in this area.

Cape Elizabeth Formation. The Cape Elizabeth Formation is well exposed in the southeastern portion of the quadrangle where it is represented by muscovite-rich schists with minor quartzite in a thick distinctly bedded sequence. On Chop Point in Woolwich the Cape Elizabeth contains a significant percentage of calc-silicate granofels just east of the faulted contact with the Cushing metavolcanics. The Cape Elizabeth as well as the Cushing Formation were originally considered by Katz (1917) to be part of the Casco Bay Group and are presently similarly considered by Hussey (1981b). (The unconformable relationship between these two map units and the quite different depositional environments they seemingly represent suggests that they should not be considered as part of the same group of formations.)

In the map area here discussed, the Cape Elizabeth represents a metamorphosed sequence of turbidity current deposits. Unlike similar sequences of rocks at approximately the same metamorphic grade, the schists of the Cape Elizabeth are generally characterized by the assemblage biotite-muscovite-quartz, the common minerals of metapelites such as garnet, staurolite, andalusite, and sillimanite being only occasionally present. Regionally, these minerals are recognized (see for example, the discussion of the geology of the Small Point area by Hussey, 1981a). Inappropriate bulk chemical composition, rather than pressure and temperature constraints imposed during regional metamorphism, explains the absence of these minerals from observed assemblages in the Cape Elizabeth Formation.

ROCKS OF THE MERRIMACK SEQUENCE

The western half of the Gardiner quadrangle is underlain by the Vassalboro, Waterville, and Sangerville Formations which together are part of the Merrimack Sequence. These metasedimentary rocks, recently described by Pankiwskyj et al. (1976), represent the post Taconic, pre-Acadian filling of a large structural basin. In the Dexter area of Central Maine and elsewhere, Merrimack Sequence rocks show evidence of soft sediment slump and clearly document an unstable depositional environment and occasionally chaotic depositional conditions. If similar evidence existed in the rocks of the Gardiner quadrangle, it has been subsequently obliterated by deformation and regional metamorphism.

Vassalboro Formation. The Vassalboro Formation was originally described by Perkins and Smith (1925) and named the Vassalboro sandstone by them. They noted (p. 222-223) a "transition zone" between the Vassalboro sandstone and the Waterville shale and defined a half-mile zone in which the two lithologies are inter-bedded. They suggested that one lithology was a more distal facies of the other or, alternatively, that the younger Waterville shale represented a gradual change in depositional environment. Regarding the relationship between the Vassalboro and the rocks exposed to the east, Perkins and Smith were less certain. They referred to these rocks as the Branch Pond gneiss for exposures of rock very different from the Vassalboro north of Palermo Village. (Presumably, the Branch Pond gneiss represents the strike extension of one or more of the lithologies here recognized as belonging to the Cushing.) They noted (p. 224) that "...the sudden change...from unmetamorphic to metamorphic rock suggests a break of some kind".

The nature of the contact between the Cushing Formation, composed of a sequence of metamorphosed volcanic and volcaniclastic rocks, and the metasedimentary rocks of the Vassalboro Formation is also unclear in the Gardiner quadrangle. Reference to the map shows an essentially north-south trending belt of folded rocks of the Cushing truncated by a discordant contact with the Vassalboro. The contact is interpreted as a folded pre-metamorphic thrust fault. If the contact represents a line separating rocks of different metamorphic grade, as suggested by Perkins and Smith from their observations in the Liberty quadrangle, a difference in metamorphic grade is certainly not in evidence in the area discussed here.

The Vassalboro Formation consists of biotite schist alternating with calc-silicate granofels. Its thickness has been estimated by Osberg (1968) to be several thousand feet. Intervals no more than 100 m in mapped thickness of rusty weathering metapelite are apparently present at numerous stratigraphic levels within the Formation. Unfortunately, the deformation of the Vassalboro and the possibility of repetition of stratigraphic units by folding prevents any definitive conclusions as to how many such intervals are present within the Vassalboro. In turn, the uncertainties arising from an incompletely understood stratigraphy hamper the recognition of such folds.

The schistose portions of the Vassalboro, usually less than 10 cm thick, are characterized by magenta hues seen readily in outcrop arising from relatively high magnesium compositions of biotite. They contain an equigranular mosaic of biotite, quartz, and plagioclase, with individual grains on the order of a millimeter in diameter. Calc-silicate intervals alternating with the schistose intervals are also, on the average, about 10 cm thick. They are characterized in outcrop by pale green colors and are frequently slightly rusty weathering due to the presence of finely disseminated pyrite. The lithology is rarely present in continuous beds. Rather it occurs in zones which in two dimensions are spindle shaped with long axes on the order of 3 meters (except where tectonically thinned to form discrete boudins). Presumably these are not spindles but rather tabular zones in three dimensions.

The geometric character of zones of calc-silicate granofels is of considerable interest. In the Berwick Formation in the Buxton quadrangle, for example, both lithic types discussed above are present. However, bedding, which is distinctly recognizable there, is generally much thicker. Within calc-silicate rich beds in the Berwick there are rod shaped zones containing calcite which weather out readily. These do not appear to be secondary deformation structures related to folding. Rather they represent either a kind of carbonate ball and pillow structure, evidence of instability during original deposition of the sediment, or solution and re-deposition of carbonate cement during diagenesis of the sediment. It seems likely that the geometry of calc-silicate rich layers in the Vassalboro is not entirely due to boudinage during deformation but may be, at least in part, due to features developed during original deposition and diagenesis of the sediment.

The textural and mineralogical character of the Vassalboro as discussed above appears to be present in all exposures mapped in the Gardiner quadrangle. Hence, to attempt the description of mappable units within the Vassalboro is neither feasible nor possible at this time except as concerns metapelitic intervals which can be, and have been, separated during mapping. These rusty weathering zones are characterized by the assemblage biotite-sillimanite-plagioclase-garnet and contain considerable pyrite. They are also characteristically graphitic.

Mapping in the Gardiner quadrangle suggests that the relationship between the Vassalboro and Waterville Formations is as interpreted by Perkins and Smith (see above). The gradational change from the Vassalboro Formation to the Waterville is best seen in a series of outcrops from Dennis Hill west to the eastern shoreline of Woodbury Pond.

In places, however, the contact is abrupt. It is marked by a strongly rusty weathering sillimanite-rich schist. Such is the case near Tacoma. Osberg (1968, p. 22) recognized a discontinuous, 0-30 m thick, black phyllite at the contact between massively bedded wackes of the Vassalboro Formation and greenish-gray phyllite of the Waterville Formation.

Where the lithologic character of the rocks changes gradually, the contact is placed where there is a significant amount of pelitic-material in each mineralogically graded bed. A typical outcrop in the transition zone has thin (1 cm thick) pelitic interbeds in which coarse "knots" of muscovite are present and which weather a rusty red color. These intervals, in which thin drag-folded quartz veins are present, alternate with slightly thicker intervals of biotite schist and 6 cm thick beds of calc-silicate granulite. These pelitic "tops" are not recognized in the Vassalboro except near its contact with the Waterville Formation.

Waterville Formation. The Waterville Formation was named by Osberg (1968) and has been estimated by him to be 1000 m thick. Because of equivocal paleontological ages based upon graptolites and inconclusive topping sense as determined from graded beds near contacts, Osberg (1968, p. 29) assumed a stratigraphy in which the Mayflower Hill Formation consisting of "heavy bedded bluish gray wacke and phyllite" was overlain by the Waterville Formation. Outcrops of the Waterville east of the Mayflower Hill seemed lithologically different from outcrops west of the Mayflower Hill. Thus he described an "eastern facies" and a "western facies" of the Waterville. The Vassalboro was considered to be younger than the Waterville. Hence the stratigraphy of Perkins and Smith (1925) and later workers (most of whom had no basis upon which to challenge the assumption of Perkins and Smith) was revised. More recently (see, for example, Osberg, 1980) the stratigraphic section has been revised with the Vassalboro Formation assumed to be older than the Waterville Formation.

That assumption has been accepted in the mapping of the Gardiner quadrangle. A thorough search for definitive data on relative age, as determined by the topping sense of graded beds at or near contacts, has thus far failed to yield confirmation of the assumed stratigraphy. However, the numerous determinations that have been made within a few hundred feet of the contact all suggest that the assumption is correct.

The Waterville Formation in the Gardiner quadrangle has been subdivided into three map units. Each is unnamed but distinct enough to allow its mapping with a fair degree of confidence. The oldest unit recognized consists of thin bedded, weakly graded calcareous siltstone and shale. In places this unit--informally named the lower pelite member--resembles the Vassalboro Formation. An impure limestone unit up to several hundred meters thick overlies this unit. Above the limestone lies a unit informally named the upper pelite member. It consists of minor calcareous siltstone and is characterized by massive, poorly sorted beds of argillaceous sandstone up to 0.3 meters thick. Because all outcrops are at sillimanite grade, this unit is characterized by rough weathering surfaces on which sillimanite porphyroblasts and pseudomorphs of coarse muscovite after staurolite stand in relief.

Sangerville Formation. The Sangerville Formation is presumed to conformably overlie the Waterville following the suggestion of Osberg (1980). The area shown on the map to be underlain by Sangerville is inferred from a few scattered outcrops in which the character of the rock is not demonstrably different from that of the upper pelite member of the Waterville. However, the area is designated as being underlain by Sangerville because of the recognized stratigraphic correlations and structural interpretations of Hussey (1981b) and Osberg (1980).

IGNEOUS ROCKS

Intrusive rocks of Ordovician(?) age. Within the Cushing Formation, but not recognized in any other mapped units in the Gardiner quadrangle, there are occasional massive lenticular bodies of plagioclase-hornblende amphibolite. The contacts of this lithology with the Cushing contain zones of very large poikiloblastic garnet up to 5 cm in diameter. The amphibolite appears to be discordant although there is a possibility that it represents several intervals of para-amphibolite within the volcanic and volcaniclastic sequence of rocks making up the Cushing. In the Cape Elizabeth area a similar lithology occurs within the Cape Elizabeth Formation. The latter has been strongly folded and if the amphibolite represents a series of intrusive sills they have also been strongly deformed obliterating any evidence that might have existed of their intrusive and/or discordant relationship to the metasedimentary rocks. At Chimney Rock in Cape Elizabeth where the unconformity between the Cushing and Cape Elizabeth Formations is well exposed, a 2 meter thick amphibolite appears to cross-cut the Cape Elizabeth and can be followed for 10 to 15 meters along the trace of the unconformity. Nowhere in the Gardiner quadrangle or elsewhere is this lithology seen in the Vassalboro or in the Waterville Formations. An Ordovician age has been suggested for these amphibolites (Newberg, 1981).

Intrusive rocks of Devonian (Acadian) age. Intrusive igneous rocks are most abundant in that portion of the quadrangle underlain by the Cushing Formation. Pegmatites of granitic composition and assumed Acadian age occur throughout the Cushing. They are common in the southwestern portion of the quadrangle where they intrude the Vassalboro but are much less common in the northwestern part of the quadrangle, an area underlain by the Vassalboro, Waterville, and Sangerville Formations. Discrete, but less abundant, pegmatites are scattered throughout exposures of the Cape Elizabeth Formation east of the Kennebec River. The reason for this distribution is unclear but perhaps related to the proximity of surface exposures to the subjacent Sebago Pluton which is generally assumed to be present in the near sub-surface. In addition to the pegmatites, a body of hornblende quartz diorite outcrops west of the City of Gardiner in the northern portion of the quadrangle. (See appendix for petrographic description of the intrusive.)

Just east of the Town of Litchfield a nearly circular body of syenite is poorly exposed in a topographic low. The intrusive was named the Litchfield Pluton by Barker (1965) who defined five variants or phases of the intrusive including magnetite-biotite syenite, foliated mafic syenite, sugary textured leucosyenite, and albite pegmatite. A Northeast Utilities Corporation report (1975) includes a potassium-argon date of 247 $\pm$ 9 m.y. (ie. an apparent Permian age). A biotite concentrate from a sample of nepheline-biotite syenite was dated. The report discusses 119 and 133 m.y. apatite fission track ages obtained earlier by Christopher (1969) on samples of biotite syenite from the same pluton in Litchfield. Although considered crystallization dates by Christopher, these dates are now considered to represent the time at which apatite cooled through a temperature of about 150 C. As discussed by Naeser and Brookins (1975), and more recently by Dallmeyer and van Breeman (1981), comparison of Rb-Sr whole rock, K-Ar, and fission track ages provides interesting information on the cooling history of Acadian intrusives in Maine. In general, Rb-Sr ages are considered to represent crystallization dates while ages obtained by the other two methods documents the post-crystallization cooling history of the rock.

The 247 $\pm$ 9 m.y. age obtained on the Litchfield pluton is assumed to represent a time at which sufficient cooling had occurred to allow the retention of radiogenic argon by biotite. The pluton is assumed to have crystallized in Devonian time. These conclusions (Northeast Utilities Corporation, 1975) are supported by the work of Dallmeyer and Van Breeman (1981) on the Togus and Three Mile Pond intrusives northeast of Gardiner in the Vassalboro 15' quadrangle. They report dates of argon retention by biotite of approximately 300 m.y. in the northern portions of the plutons and 265 m.y. in the southwestern portions of the plutons. Thus there is a southwest "younging" of argon retention dates which is consistent with the still younger age obtained on the Litchfield pluton.

It seems reasonable to infer a Devonian crystallization age for the Litchfield pluton as the 1975 report suggests. However, to consider it a part of the Bays-of-Maine igneous complex (Chapman, 1968) is unwarranted in view of the geographical restrictions inherent in Chapman's use of the term for intrusives northeast of Penobscot Bay. Futhermore, the relationship of the pluton to others nearby, let alone to those northeast of Penobscot Bay, is at present unknown.

Intrusive rocks of Mesozoic age. Basaltic dikes of presumed Mesozoic age occur rarely in the area mapped. The largest of these is approximately 20 m thick and outcrops along Cathance Stream 4 km below Meacham Pond. The dike is poorly exposed but on the basis of float can be assumed to continue to Richmond Corner where it is exposed on both the east and west sides of Route 138 just south of the junction with Route 197. Other smaller dikes have been observed in the road cuts along I-95 and elsewhere but, are not shown on the map accompanying this report.

METAMORPHISM

The regional metamorphism of the rocks exposed in the Gardiner quadrangle has not been given a great deal of attention. Rocks of appropriate aluminous compositions such as the "upper pelite" member of the Waterville (Sangerville?), the pelite in the Nehumkeag Pond member of the Cushing Formation, and portions of the Cape Elizabeth Formation all contain abundant sillimanite invariably accompanied by garnet. Hence it is assumed that all the rocks exposed in the area mapped are at sillimanite grade. Whether or not there is evidence for the breakdown of muscovite to sillimanite plus potassium feldspar is not known. The fact that in some areas the rocks are extremely migmatized suggests that possibly some of the rocks are at second sillimanite grade. However, the migmatized areas which have a great deal of pegmatitic material mixed with the metasediment and metavolcanics do not necessarily imply derivation of granitic melt by partial melting of the metasediments. On the contrary, contacts with pegmatites are locally very sharp and suggest that the melts from which they crystallized are not of local derivation ie., anatectic melts. Their crystallization temperatures were more than likely well below the temperature at which muscovite breakdown occurs.

In the northwest part of the quadrangle, thin section examination of the Waterville Formation indicates that in many places there is evidence of pseudomorphs of randomly oriented coarse grained muscovite after staurolite porphyroblasts. Novak and Holdaway (1981) have discussed the metamorphism of the rocks in the Augusta quadrangle immediately north of the area mapped. They recognize three metamorphic events in the area, the second of which was a sillimanite-producing event of regional extent with an apparent heat source "to the southeast" (1981, p. 51). The northwest portion of the Gardiner quadrangle is likely south of their "staurolite-out" isograd and also south of their recognized "sillimanite-in" isograd which is an isoreaction-grad based upon the following reaction:

musc. + staur. + chlor. = sill. + bio. + quartz + H_2O

While there appears to be a uniformity of pressure and temperature attained by the exposed rocks in the Gardiner Quadrangle during prograde metamorphism, such is not the case for retrograde metamorphism. Retrograde effects are documented petrographically primarily by the partial replacement of garnet porphyroblasts by chlorite as well as the replacement of biotite and amphibole by chlorite. These affects are spatially associated with observed cataclastic textures in the rocks. Thus chlorite is common in the rocks along the Kennebec River which in the southeast part of the quadrangle follows the Eastern River Fault and the faults related to the Norumbega Fault system. Retrograde chlorite is common as well in the exposures along the east side of Pleasant Pond in the north-central part of the quadrangle where post-metamorphic faulting has occurred.

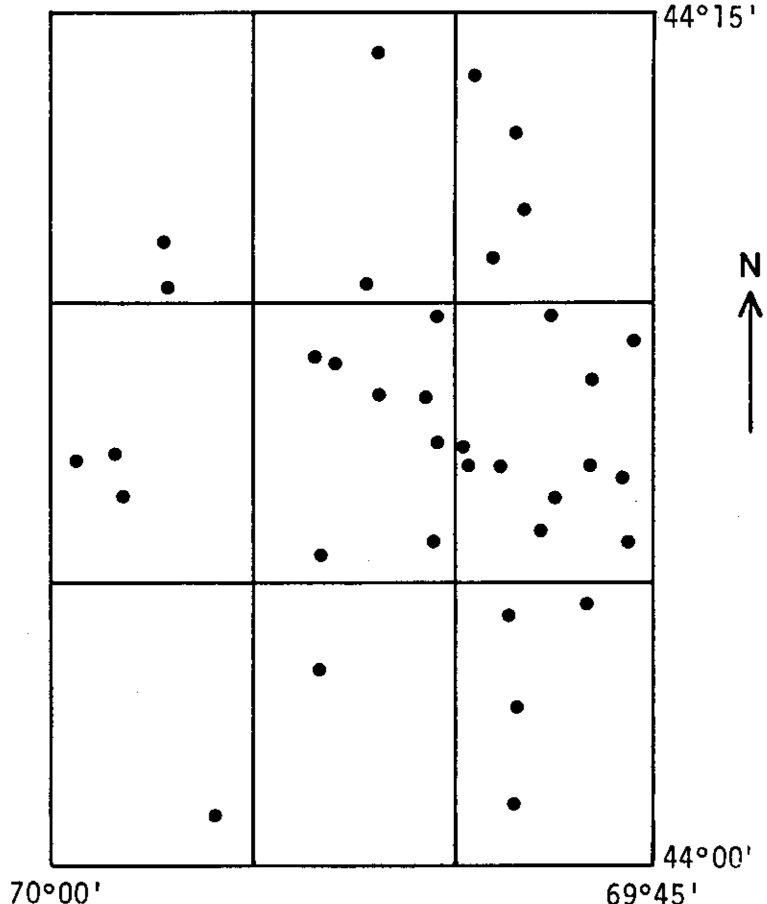
STRUCTURE

The major structural features of the Gardiner quadrangle have been summarized previously (Newberg, 1981). Three episodes of folding are recognized. The first involved the development of large scale recumbent folds. The evidence for these folds has been discussed by Osberg, (1980). No compelling evidence of such an early event is recognized in the Gardiner quadrangle but it is assumed to have affected the area discussed here because: 1) it is a regionally recognized event; and 2) a band of Vassalboro Formation rocks exposed in the Oak Hill area in the northwest part of the quadrangle appears to core a southwest plunging structure which is interpreted to be a synform on the basis of poorly defined topping sense in the rocks of the limbs of the structure. West of the axis, weakly graded beds indicate a west topping sense while east of the axis the topping sense is east. Both limbs dip steeply toward the structural axis. North of Tacoma on the east flank of Woodbury Hills, a strong preferred orientation of sillimanite is present plunging southwest. A similar sillimanite lineation is observed in outcrops 0.8 km. west of Litchfield. Microscopic examination of these rocks suggests that the sillimanite developed essentially contemporaneously with "F-2" folding (see above discussion of metamorphism). The fibrolite is interpreted to have nucleated and grown at the intersections between bedding (or earlier "F-1" cleavage) and F-2 cleavage. Since F-1 cleavage and bedding are essentially parallel except in the seldom seen hinges of early recumbent folds the attitude of sillimanite is taken as an indication of F-2 fold plunges. The coarse pseudomorphs of muscovite after staurolite seen elsewhere in the Waterville metapelites show no indication of mechanical disruption which is taken as additional evidence of the essential contemporaneity of F-2 folding and the sillimanite-forming metamorphic event discussed above.

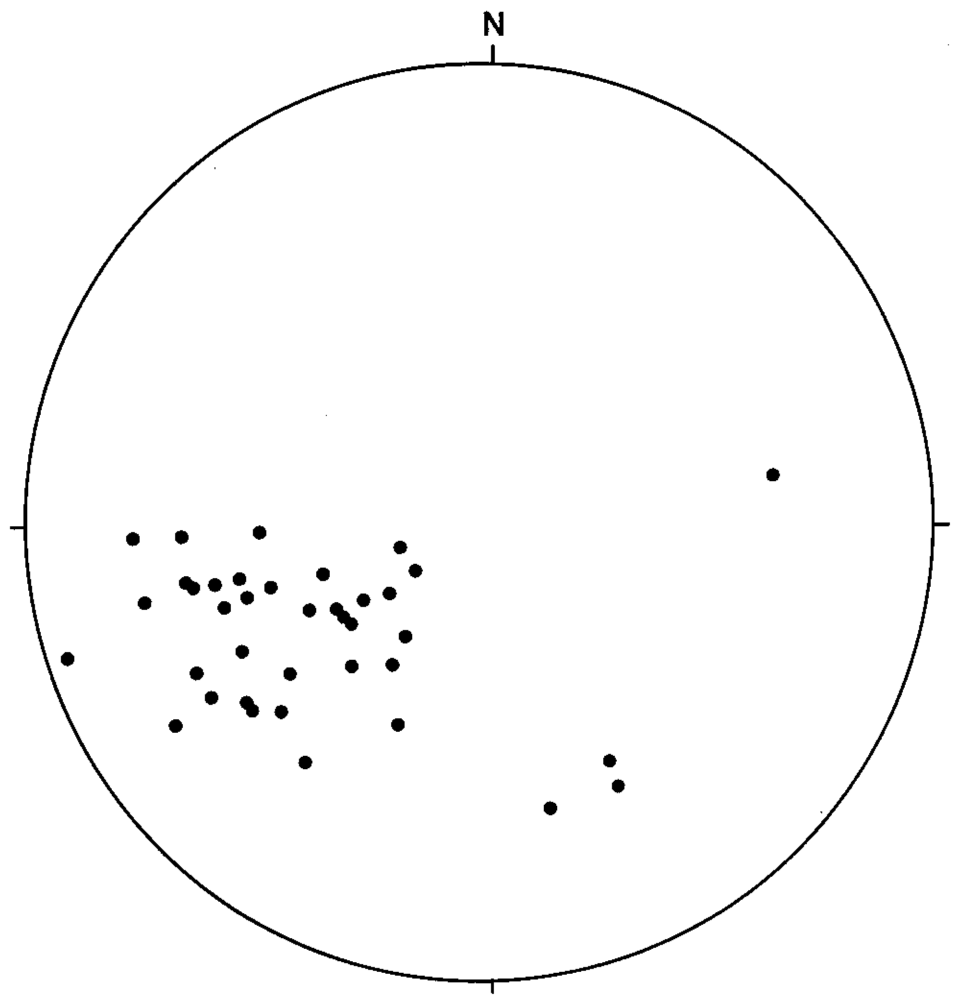
Since this structure and similar ones identified in the quadrangle are upright to slightly overturned isoclinal structures they could not be responsible for inversion of the stratigraphy. Hence they are F-2 structures and refold earlier, very much larger, recumbent F-1 folds. The structural interpretation discussed here has recently been challenged by Hussey (personal communication) who interprets the Vassalboro of the Oak Hill area as lying in the axial portion of a northeast plunging anticline on the basis of lineation attitudes in the Lewiston quadrangle on strike to the southwest.

A third fold event has affected the rocks of the Gardiner quadrangle and is represented by the crenulation of F-2 cleavage in the metapelites and by outcrop scale folds with northwest plunging axes and northeast dipping axial surfaces. This event, designated "F-3", is not everywhere evidenced in outcrop (see Fig. 1). In general, where these small folds are particularly abundant there are also numerous granitic pegmatites exposed. Some exposures document F-3 folding of the pegmatites as well as showing pegmatites cutting F-3 folds. The close temporal and spatial association of Acadian plutonism and this fold event is similar to that discussed by Moench and Zartman (1976, p. 219) for northwestern Maine.

Gardiner 15' Quadrangle



Location Map



Southern hemisphere equal area projection
of poles to axial surfaces.

Figure 1. Location and orientation of F-3 fold structures

The three episodes of folding discussed above can be clearly seen in the Merrimack Group rocks in the western half of the quadrangle. East of the faults marking the topographic low along Upper and Lower Pleasant Pond i.e., within the metavolcanics and metasediments of the Cushing Formation, only the youngest event is recognized. Older fold structures are present and are mapped (see map), but their equivalence with "F-1" and "F-2" folds as described above cannot be demonstrated. Both Hussey (1981b) and Osberg (1980) have suggested pre-Merrimack Group deformation of the Cushing Formation and Casco Bay Group rocks.

At Chimney Rock in Cape Elizabeth (see location map, Fig. 2) an unconformity between the older Cushing felsic metavolcanics and the younger Cape Elizabeth metasedimentary rocks is well exposed. Relationships observed there suggest that deformation post-dating the deposition of the Cape Elizabeth, and presumably other units within the Casco Bay Group, is sufficiently intense to have obliterated any previous deformation patterns that may have existed in the Cushing. The same problem exists for the boundary between the Casco Bay Group rocks and lithologies of the Vassalboro Formation. In the Gardiner quadrangle, units of the Vassalboro are in contact with the Cushing along the Pleasant Pond topographic lineament referred to above. Either the Casco Bay Group rocks were removed by erosion prior to deposition of Vassalboro lithologies, or they have been eliminated by faulting subsequent to their deposition. In short, the Cushing-Vassalboro contact exposed in the Gardiner Quadrangle represents either a folded unconformity or a folded early thrust fault. The lack of supporting evidence of the former has led most people engaged in field mapping in the area to assume that these two units are thrust contact (see, for example, Doyle 1967). Since thrust faults characteristically involve - as a matter of definition almost - the tectonic emplacement of older stratigraphic units over younger, it has been assumed that the Cushing units have been thrust westward over the Vassalboro units. There is, however, no compelling evidence to suggest that the younger Vassalboro has not been thrust eastward over the older Cushing. Thus, while there is general agreement that a major structural break separates these two very different sequences of lithologies, the direction of tectonic transport has yet to be demonstrated.

The favored interpretation of this writer is that the Vassalboro is structurally (as well as stratigraphically) above the Cushing, having been tectonically transported from west to east. The evidence for this is tentative. First, the contact between the Vassalboro and Cushing lithologies truncates the patterns of units mapped in the latter formation yet parallels the pattern of units mapped within the Vassalboro to the west. It would seem mechanically easier for the Vassalboro to have been detached at a particular stratigraphic level and transported eastward over the previously deformed Cushing lithologies. The alternative i.e., detachment of the Cushing along a stratigraphically discordant zone with westward tectonic transport seems less likely. Second, the rusty weathering metapelite in the Vassalboro which appears to sole the thrust in the northeast part of the quadrangle contains one to two feet long ellipsoidal blocks of marble and amphibolite which represent tectonic "rafts" of the Cushing (Newberg, 1981 p. 4). These observations are not particularly compelling as one could readily argue that blocks of the Cushing have been torn loose and incorporated in the developing Vassalboro

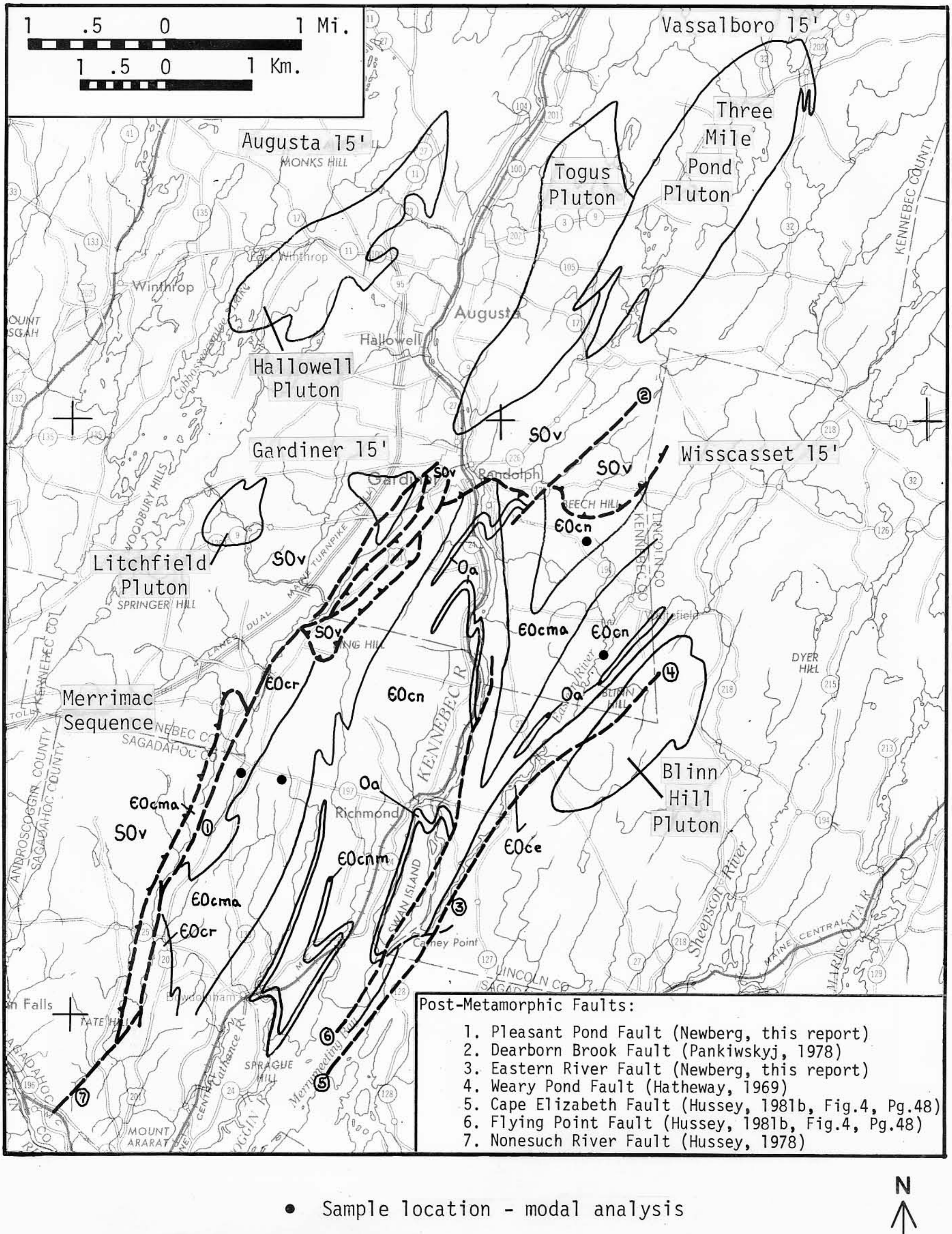


Figure 2. Index to locations and geologic features described in text. (for explanation of geologic labels, see text and accompanying geologic map).

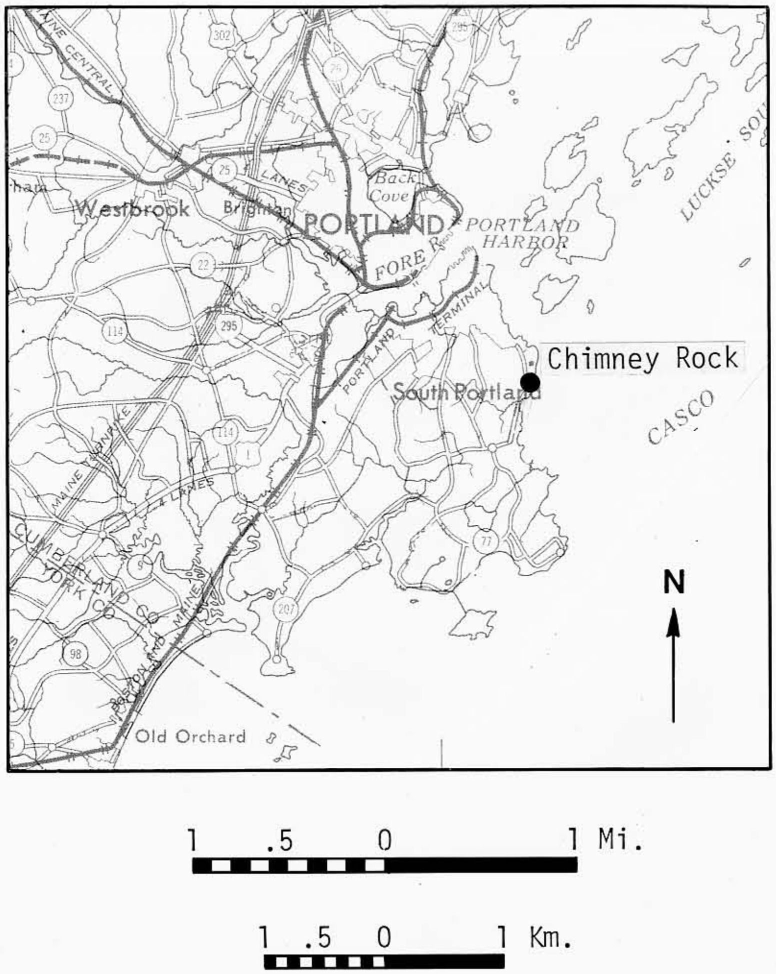


Figure 2. Continued. Index to locations and geologic features described in text.

sediments as the Cushing over-rode the depositional basin travelling from east to west. Third, lineations and minor fold axes observed in outcrops between Ring Hill and Pleasant Pond suggest that the structure in that area is dominated by a north plunging syncline with the Vassalboro along the axial trace of the structure and Cushing lithologies on the limbs.

The problem of the Vassalboro-Cushing boundary is, therefore, far from resolved. It would appear that it is best addressed in the Liberty 15' quadrangle (see Fig. 2) where Pankiwskyj (1978, Fig. 2) has mapped two small fault bounded areas of Vassalboro within the Cushing north of the Village of Palermo.

The fault discussed above represents the only early, pre-metamorphic fault identified in the Gardiner quadrangle. The other faults shown on the map accompanying this report are all post-metamorphic faults. (This does not, however, preclude a pre-metamorphic existence for any of the structures shown.) They are variously characterized by cataclasis, sulfide mineralization consisting chiefly of pyrite, brecciation, and, in some cases, quartz veining. All appear to have associated retrograde metamorphism as there is fracture-related chloritization of biotite, hornblende, and garnet where these minerals are present. Repetitive displacement is indicated in a few places. It is particularly apparent on the east side of the Kennebec River at Carney Point. Here a silicified breccia is exposed in which the angular fragments are dark, flinty ultramylonite.

Thin sections of rocks showing catalastic texture reveal varying degrees of crushing and granulation of the feldspars and micas with bands of sutured quartz grains possibly representing recrystallization of silica. Where cataclasis is extreme, a dark, sub-microscopic matrix is present in which angular remnant fragments of quartz and feldspar are often present. Melting of the rock to yield pseudotachylite cannot be verified. However, the relationships seen in outcrop i.e., thin, well-defined, cross-cutting "dikes" which are not connected by through-going fractures, are more consistent with frictional melting and local "intrusion" of the melt than extreme mechanical granulation.

The various faults mapped in the Gardiner quadrangle are assumed to be part of the Norumbega Fault system as named previously by Stewart and Wones (1974). Figures 2 and 3 show the location of regionally important fault structures and the names proposed for them.

The attitudes of joints have been measured. A summary stereographic projection of their orientations is given in Fig. 4. An index map also indicates the number of surfaces which were slickensided and the location of these surfaces. Joint orientation as a function of location in the quadrangle was examined to see if systemmatic changes in attitude might suggest directions of relative displacement along mapped, or previously unrecognized, structures. In plotting joints for each 1/9 of the quadrangle, no systemmatic changes in orientation as a function of location in the quadrangle can be seen.

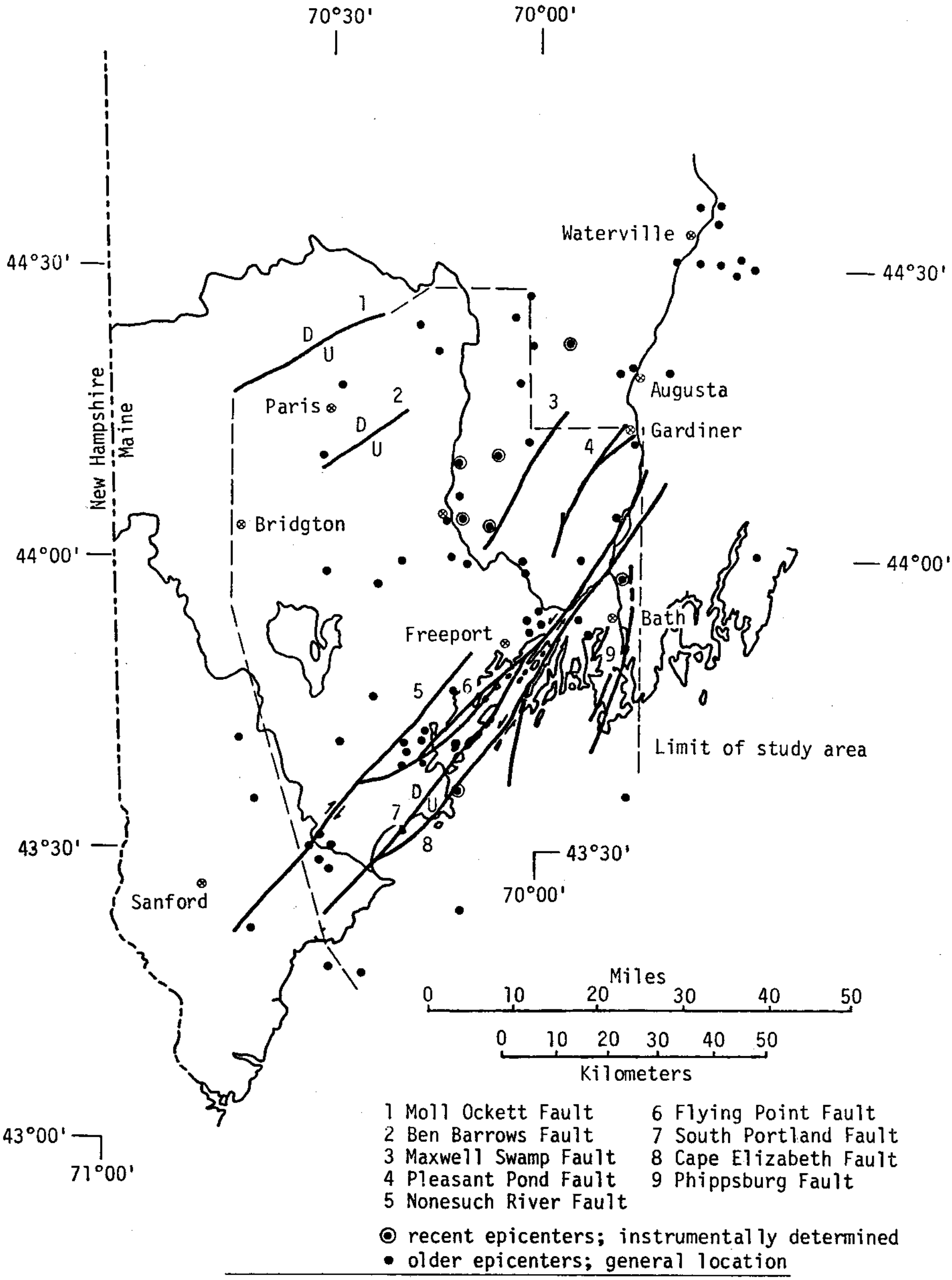
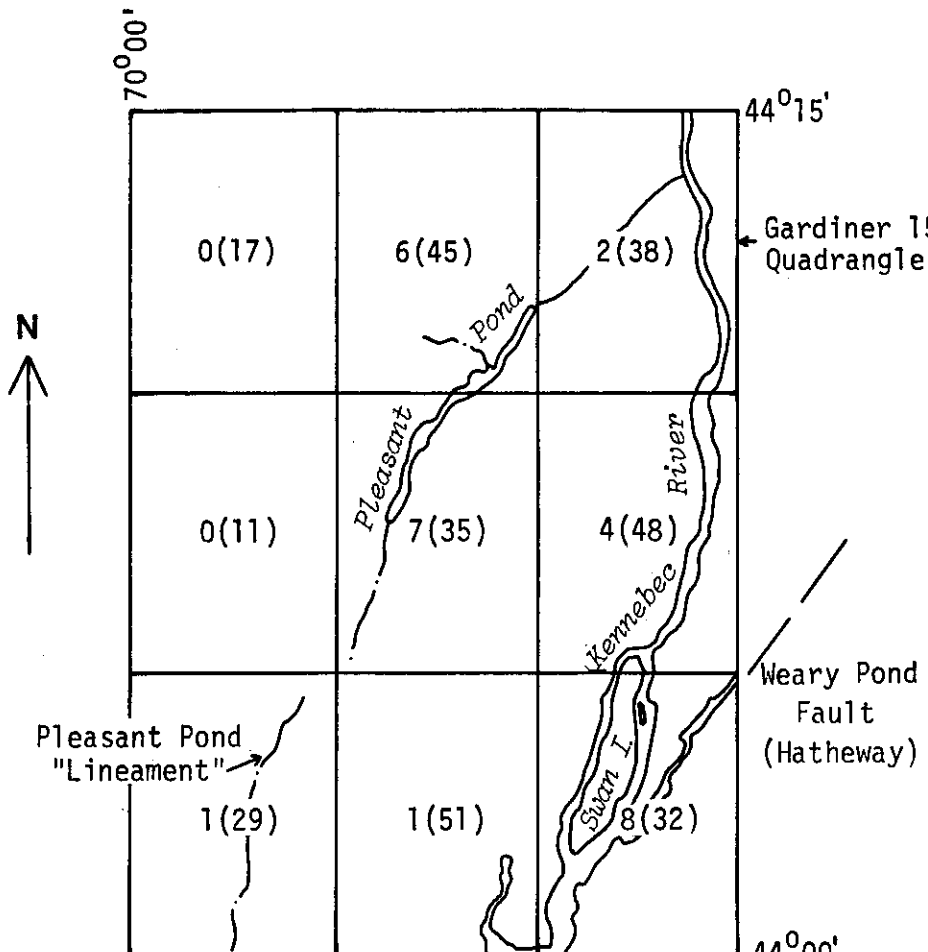
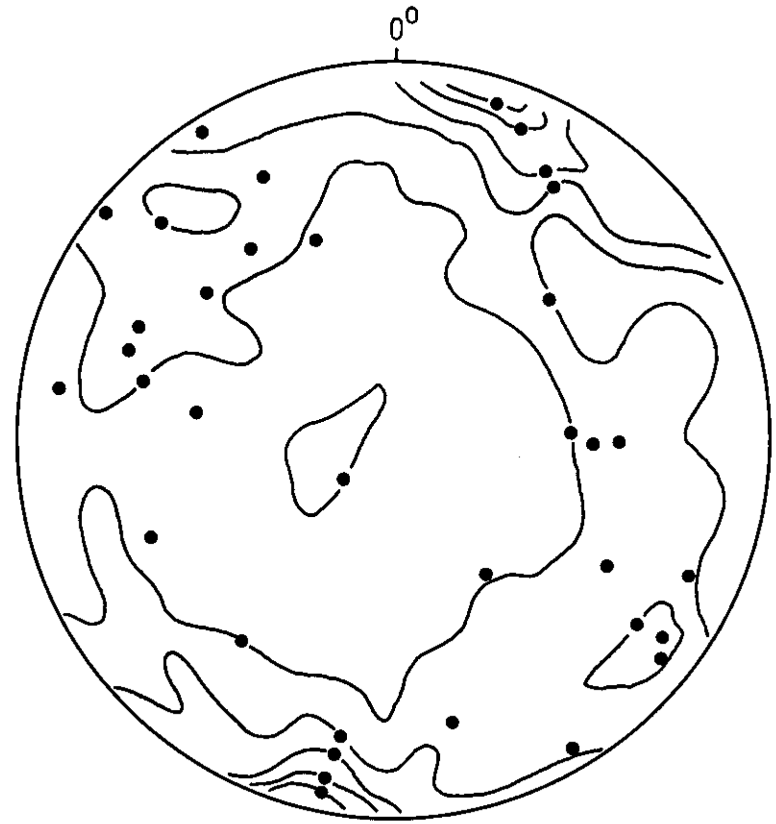


Figure 3. Locations of earthquake epicenters (1776-1979) and postmetamorphic faults in the Lower Androscoggin Valley - Casco Bay area (Figure 4. of Hussey, 1981b).



Number of slickenslided fracture surfaces measured with total number of measured surfaces in parentheses.



Southern hemisphere equal area projection of poles to 306 joints in the Gardiner Quadrangle - solid circles are poles to slickenside surfaces.

Contour Interval 2%

Figure 4. Joint orientations in the Gardiner 15' Quadrangle.

Observed surfaces which are slickensided are plotted in Figure 4 as well. Although variably oriented, such surfaces tend to strike northeast and to dip steeply northwest or southeast. Their orientations are thus the same as the faults or fault zones hypothesized for the Pleasant Pond and lower Kennebec River topographic lineaments (ie., for the Norumbega Fault Zone). Slickensides in the surfaces have a considerable variation in pitch although in general it is steep with both up and down-dip movement indicated.

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APPENDIX

Magnetic data - Gardiner quadrangle

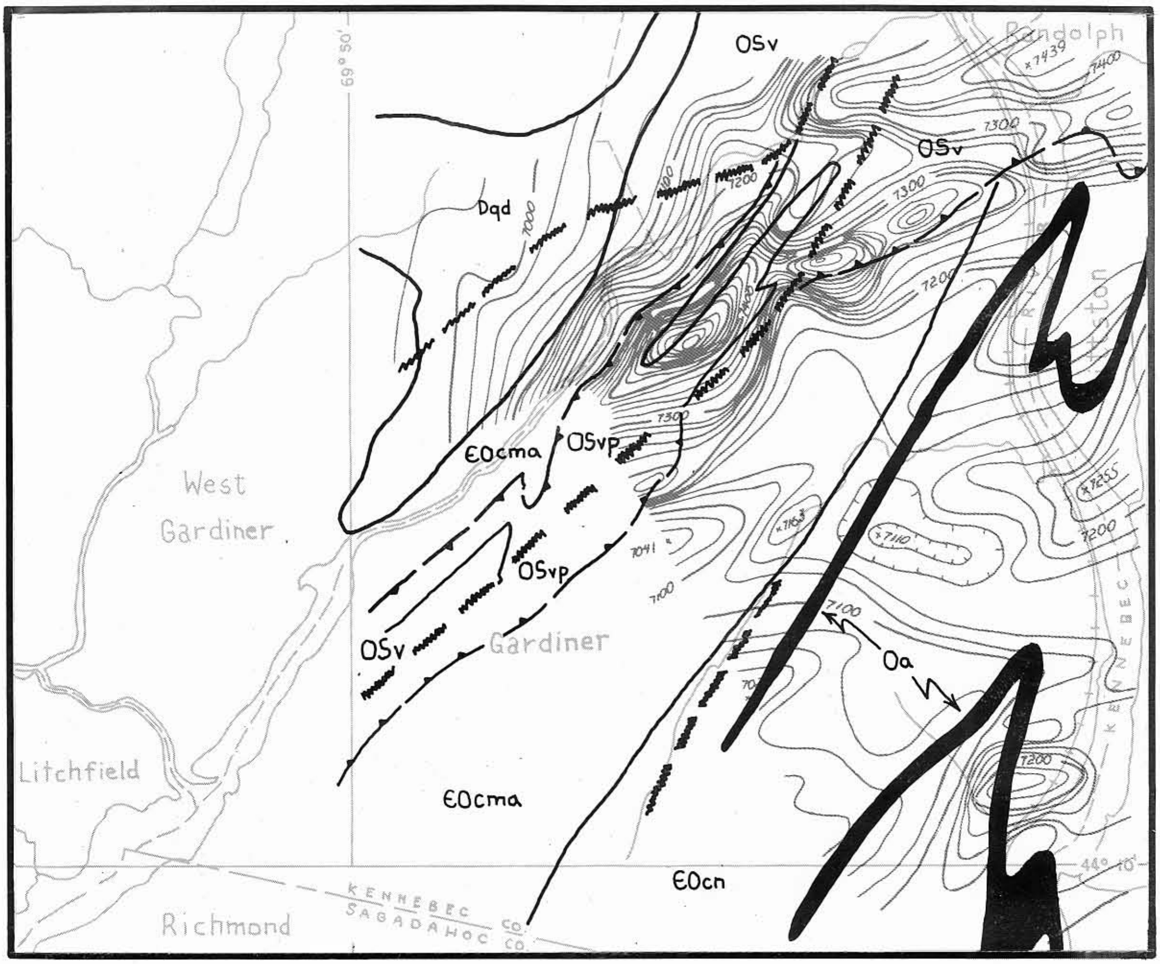
Wing (1959) has discussed the results of an airborne magnetic survey conducted over a portion of the NE 1/4 of the Gardiner quadrangle. His interpertation was that the magnetic highs (see appendix Fig. 1) were an expression of the trend of a rusty weathering schistose lithologic unit containing significant pyrrhotite.

Although the correlation is not particularly good, there is a tendency for magnetic highs to follow the trace of the thrust fault shown in Figure 1. The anomalous magnetic properties would therefore be explained by the abundant pyrrhotite contained in the metapelite of the Vassalboro Formation which appears to sole the thrust in this area. However, the use of the aeromagnetic patterns in this area as a determinant of lithologic configuration and therefore of bedrock structure is questionable. For example, there is no expression in the magnetic data of the amphibolite dikes (?) of possible Ordovician age which intrude the Nehumkeag Pond member of the Cushing. One might reasonably expect the susceptibility contrast between the felsic metavolcanics of the Nehumkeag Pond and the massive hornblende-plagioclase amphibolites to be sufficient to show the distribution of these two units. In addition, the 7200 + gamma magnetic high in the southeast corner of the survey area (see appendix Fig. 1) shows a remarkably good correlation with the topography i.e., with a ground moraine mantled, bedrock-cored (?) hill. Elsewhere there are less striking correlations between magnetic patterns and topographic features. In short, the magnetic patterns do not seem to be satisfactorily explained by bedrock features. Rather it seems likely that they are derived in a very complex way from lithologic character of the bedrock, topography, type and amount of glacial overburden, and variation in distance between the aircraft flying the magnetometer and the ground. The fact that such a small area has been surveyed also restricts the ability to resolve the effects of these several variables upon the magnetic patterns observed.

Miscellaneous Petrographic Data - Gardiner quadrangle

An attempt has been made to better characterize the map units shown in the Gardiner quadrangle by doing modal analyses of samples of the various units. The following descriptions and modal analyses provide preliminary data in the sense that more analyses are required before any conclusions can be drawn as to how well they reflect the mineralogical character of the units they represent.

Cushing Formation, Richmond Corner Member. Sample #7-143; location: outcrop on east side of U. S. Route 201 approx. 0.5 km south of Richmond Corner (intersection of U. S. Route 210 and Maine Route 197). The rock is a medium gray granofels characterized by scattered large garnets up to 4 mm in diameter. Compositional banding is poorly expressed in outcrop, and individual hand specimens display massive texture. In thin section the large garnets have a poikiloblastic character containing small inclusions of quartz (the only quartz observed in this thin section). They are anhedral and faintly compositionally zoned. The hornblende occurs as ragged anhedral grains with numerous inclusions of plagioclase and magnetite. The grains have long dimensions of up to 1 mm.



1 .5 0 1 Mi.   1 .5 0 1 Km.

Flight interval:
0.25 to 0.50 miles

Flight altitude:
500 feet above terrain

15° 57,000 approx. inclination & total intensity

16° approx. mean declination 1959

Regional Magnetic Values

Contour interval 20 gammas based on total intensity less 50,000 gammas

Intrusive Rocks:

Dqd Hornblende quartz diorite
Oa Amphibolite

Metasedimentary & Metavolcanic Rocks:

Osv Vassalboro Fm.
Osvp Vassalboro Fm., pelitic schist
ЄOcn Cushing Fm., Nehumkeag Pond Member
ЄOcma Cushing Fm., Mt. Ararat Member

"Early" thrust fault, teeth on upper plate

"Late" high angle fault

Geologic contact

Appendix Fig. 1. Aeromagnetic contours of Wing (1959) compared with pattern of lithologic units as mapped by Newberg (this report).

Plagioclase has a mutual boundary relationship with hornblende. It is frequently twinned and from symmetrical extinction angles of albite twin lamellae its composition is An_{55-60}.

The mode given below was obtained by counting 1000 points. Point spacing was 0.66 mm and traverse spacing was 0.6 mm.

garnet	3.1
apatite	1.7
hornblende	52.2
plagioclase	33.0
quartz	0.7
magnetite	9.3
	100.3

Cushing Formation, Mt. Ararat Member. Sample #7-91-1; location: outcrop on east side of exit ramp north bound, I-95 at Richmond - Litchfield interchange, approx. 0.5 km south of Maine Route 197. The rock is a compositionally banded, medium gray, biotite granofels. Hornblende crystals up to 0.5 mm in long dimension characteristically occur in random orientation on foliation surfaces defined by sub-parallel orientation of biotite. Compositional banding in the Mt. Ararat member results from variation in quartz and plagiolase (An_{40}) biotite ratios. Accessory magnetite occurs as irregular masses within subhedral sphene.

The mode given below was obtained in the same manner as that given above.

apatite	2.0
hornblende	32.9
plagioclase	44.1
quartz	6.5
biotite	11.4
sphene	2.2
magnetite	0.9
	100.0

Cushing Formation, Mt. Ararat Member. Sample #7-91-2; location: sample collected a few feet from that described above. As previously noted in the description of this member of the Cushing (see page 5), amphibolite comprises an estimated 40% of the unit. This sample contains hornblende crystals up to 2 mm in long dimension in sub-parallel orientation. The hornblende contains small subhedral inclusions of apatite. Plagioclase occurs as 0.3 mm irregular grains, interstitial to hornblende. In this section they are untwinned. Modal percentages are as follows:

apatite	1.1
hornblende	67.2
plagioclase	10.3
biotite	21.3
opaques	0.1
	100.0

Cushing Formation, Nehumkeag Pond Member. Sample #0-356; location: outcrop on north side of Maine Route 194 in the Town of Pittston, Wiscasset 15' quadrangle. The outcrop is east-northeast of Goodspeed Cemetery. The rock is moderately rusty weathering, has a weak foliation and planar fabric defined by parallel oriention of biotite and muscovite in 1-2 mm thick bands which separate light colored bands of quartz and feldspar which are up to 7 mm thick. The rock has a blocky prismatic break (along foliation and joint surfaces) and is uniformly fine grained (0.3 mm). The banding in the rock is defined (in thin section) by varying feldspar ratios...from 100% plagioclase to 50% plagioclase, 50% potash feldspar. The percentage of quartz does not appear to vary from one compositional band to the next. Garnet occurs as ovoid "grains" containing inclusions of an unidentified opaque mineral and their form, as well as the general character of the texture as viewed micoscopically, suggests mild cataclasis. The mode is as follows:

garnet	0.2
plagioclase	37.8
potash feldspar	9.6
quartz	40.0
biotite	9.2
muscovite	1.4
pyrite	1.8
	100.0

Cushing Formation, Nehumkeag Pond Member. Sample "Cunp"; location: outcrop on east side of Eastern River in the Town of Pittston, Wiscasset 15' quadrangle, approximately 3.3 km south of the Village of East Pittston (Maine Route 194). The characteristics of this sample are much the same as that described above although more intense cataclasis is evidenced by the textural relationships. Ragged potash feldspar crystals (up to 0.5 mm in diameter) show microcline twinning and numerous angular inclusions of quartz and plagioclase which are less than 0.1 mm in diameter. This is characteristic also of the sample described above. The mode is as follows:

garnet	1.1
plagioclase	10.2
potash feldspar	23.4
quartz	44.6
biotite	11.0
muscovite	9.6
pyrite	0.1
	100.0

"Hornblende quartz diorite". Sample #G9-97; location: 300 meters southeast of the Pond Road in W. Gardiner on cottage access road...access road is approximately 900 m southwest of Pond Road overpass of I-95. The rock is a weakly foliated porphyritic, medium gray intrusive. Growth-zoned and twinned (pericline and albite twin laws) plagioclase crystals are up to 3 mm in long dimension, have euhedral to subhedral form, and occur as phenocrysts in a groundmass composed of 0.5 mm crystals of quartz, biotite, and plagioclase. Twinned and growth-zoned euhedral allanite crystals are occasionally present surrounded by fine-grained epidote. Biotite occurs as plates up to 0.5 mm long, frequently containing 0.1 - 0.2 mm long prismatic euhedral to subhedral apatite. The biotite shows sub-parallel orientation thus defining the weak foliation noted above. Textural relations suggest that the intrusive is post-tectonic (i.e., late Acadian) in age. The mode is as follows:

plagioclase	49.9
potash feldspar	0.1
quartz	17.3
biotite	24.6
hornblende	3.8
apatite	1.7
sphene	2.4
epidote	0.2
	100.0